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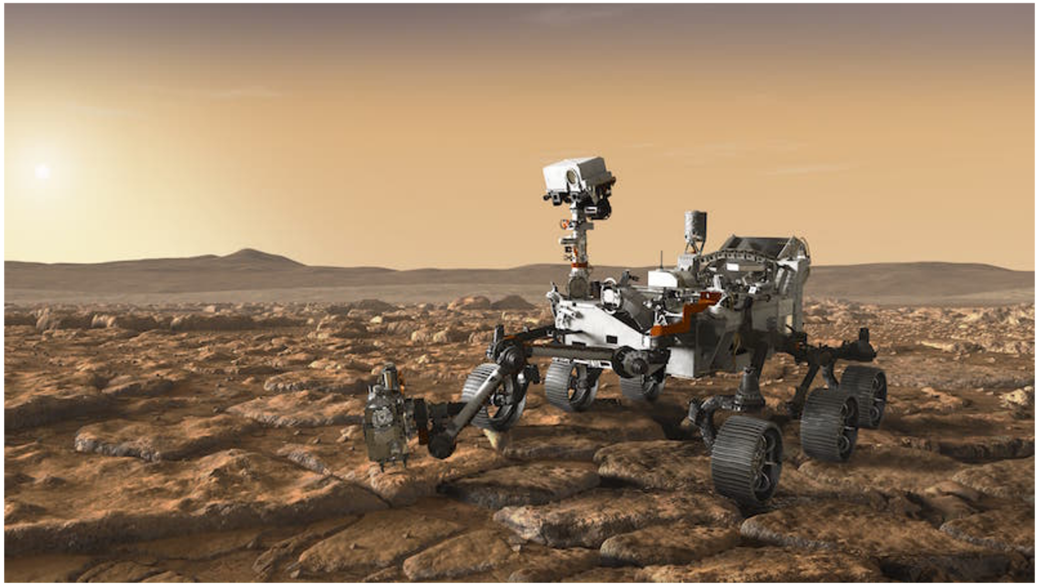

Probabilistic Kinematic State Estimation for Motion Planning of Planetary Rovers

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Mars Rover Collision Checker (ACE)

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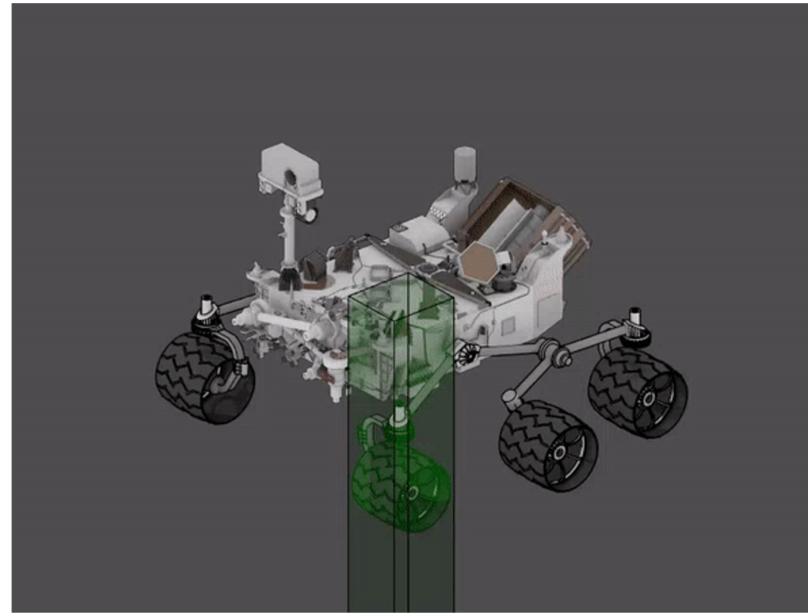
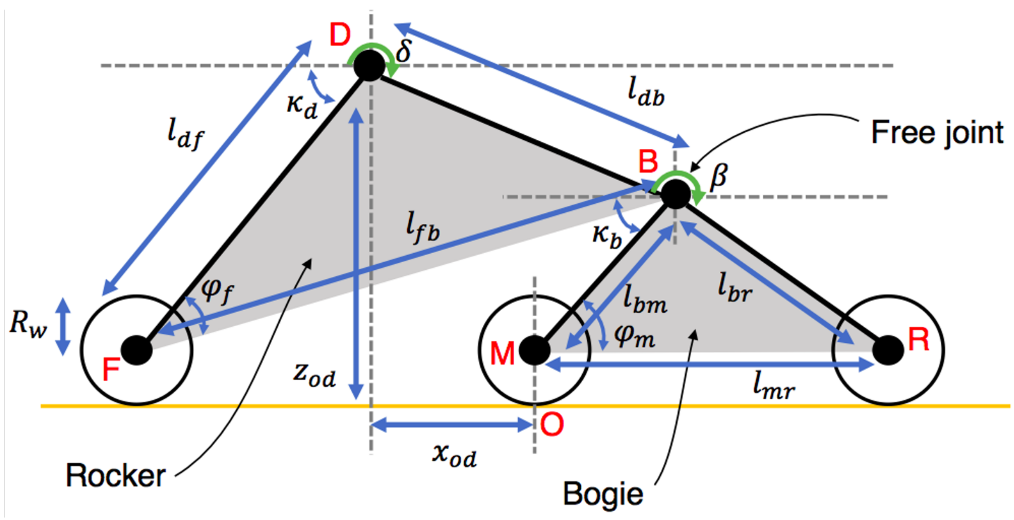
- Accurate inverse-kinematics solution using iterative nonlinear optimization is intractable on slow spacecraft computers (*e.g.*, RAD750)

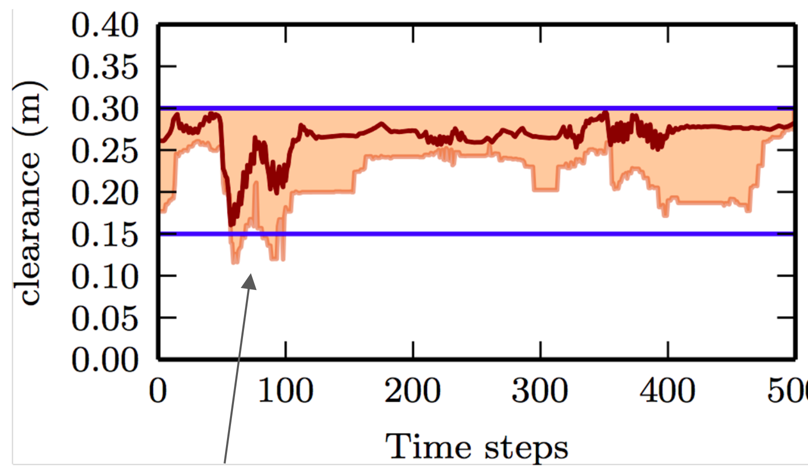
- ACE (Approximate Clearance Evaluation) obtains worst-case bounds on bounds on vehicle clearance, attitude, and suspension angles *without iterative computation* from wheel heights.



Courtesy: Guillaume Matheron and Olivier Toupet



ACE solves the inverse-kinematics problem using the wheel height and the known rocker-bogie differential geometry



Constraint violation (conservative)

Simplified Overview of ACE

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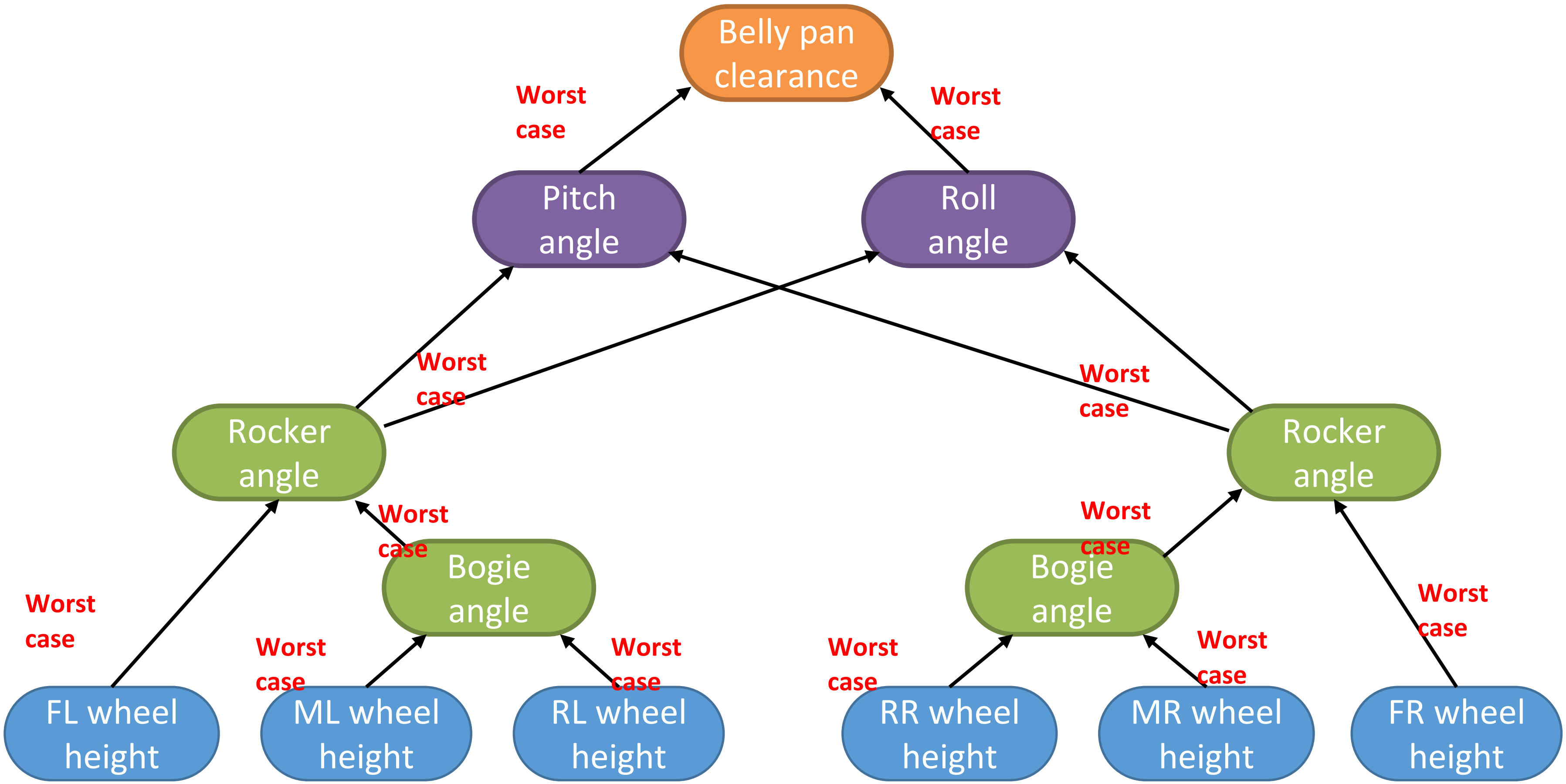


Combining worst-case values of multiple parameters leads to over-conservatism → False positives during collision checking

Probabilistic ACE (p-ACE)

- Instead of computing deterministic worst-case ranges of state, we estimate probability distributions over state.

- The distributions (learned offline from simulations) can be used to compute the probability of “constraint satisfaction”, thereby relaxing the hard ACE bounds.

Joint State   Rover Pose

$$\mathbb{P}(\omega \in \Omega | \mathbf{x}, m) = \int_{\omega \in \Omega} p(\omega | \mathbf{x}, m) d\omega$$

Allowable State Range   Map

Candidate path from motion planning algorithm:

$$X = \{\mathbf{x}_0, \mathbf{x}_1, \cdots, \mathbf{x}_k, \cdots\}$$

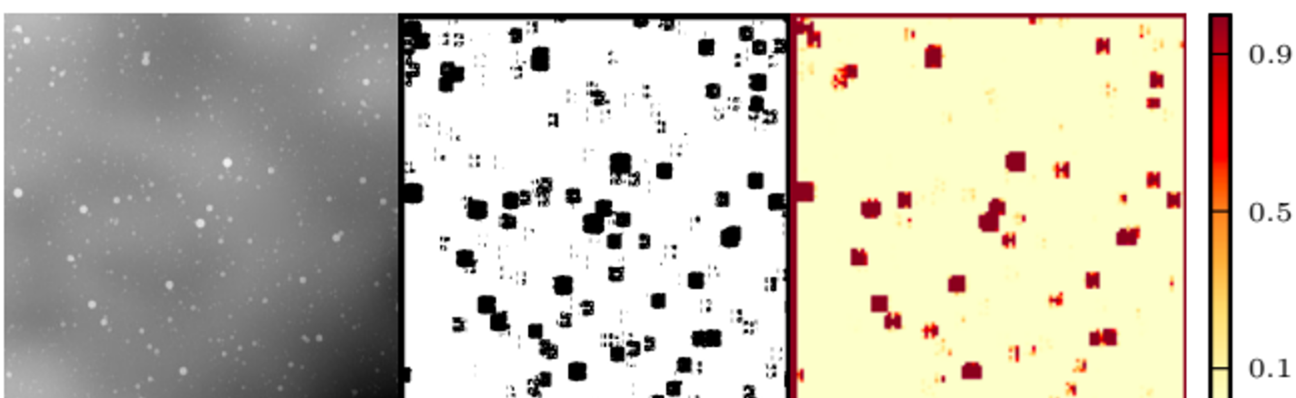
Risk evaluation:

$$R(X) = \max_k \mathbb{P}(\omega \notin \Omega | \mathbf{x}_k)$$

Collision free if:

$$R(X) < r$$

Threshold: Risk factor



- **Left**: Depth Elevation Map
- **Middle**: ACE collision map in C-space (black = inaccessible, white = accessible)
- **Right**: p-ACE (probabilistic) collision map drew as a heatmap in C-space

Results (ACE vs p-ACE)

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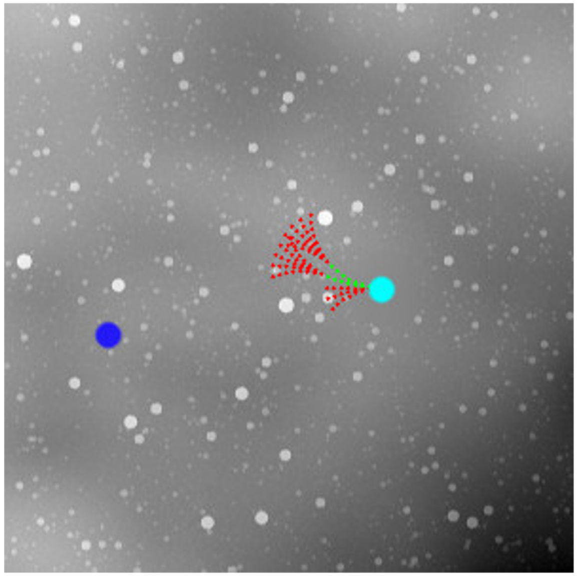
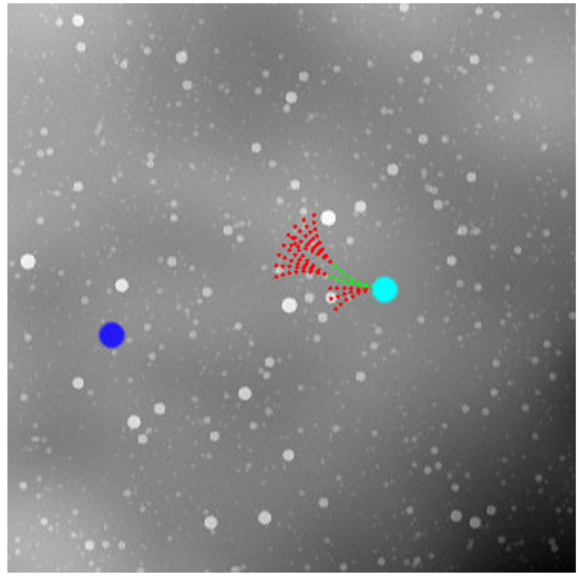
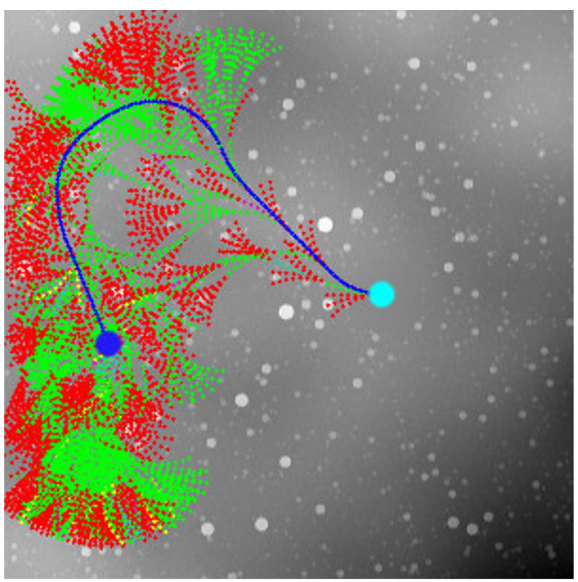


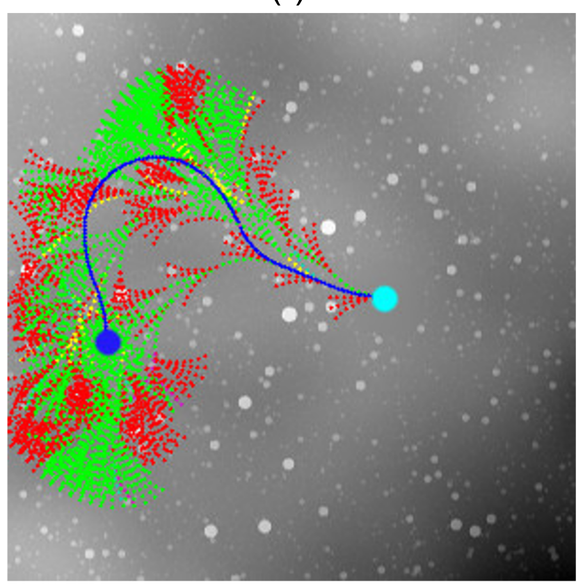
Deterministic



Risk/m (r): 1e-06



Risk/m (r): 1e-04



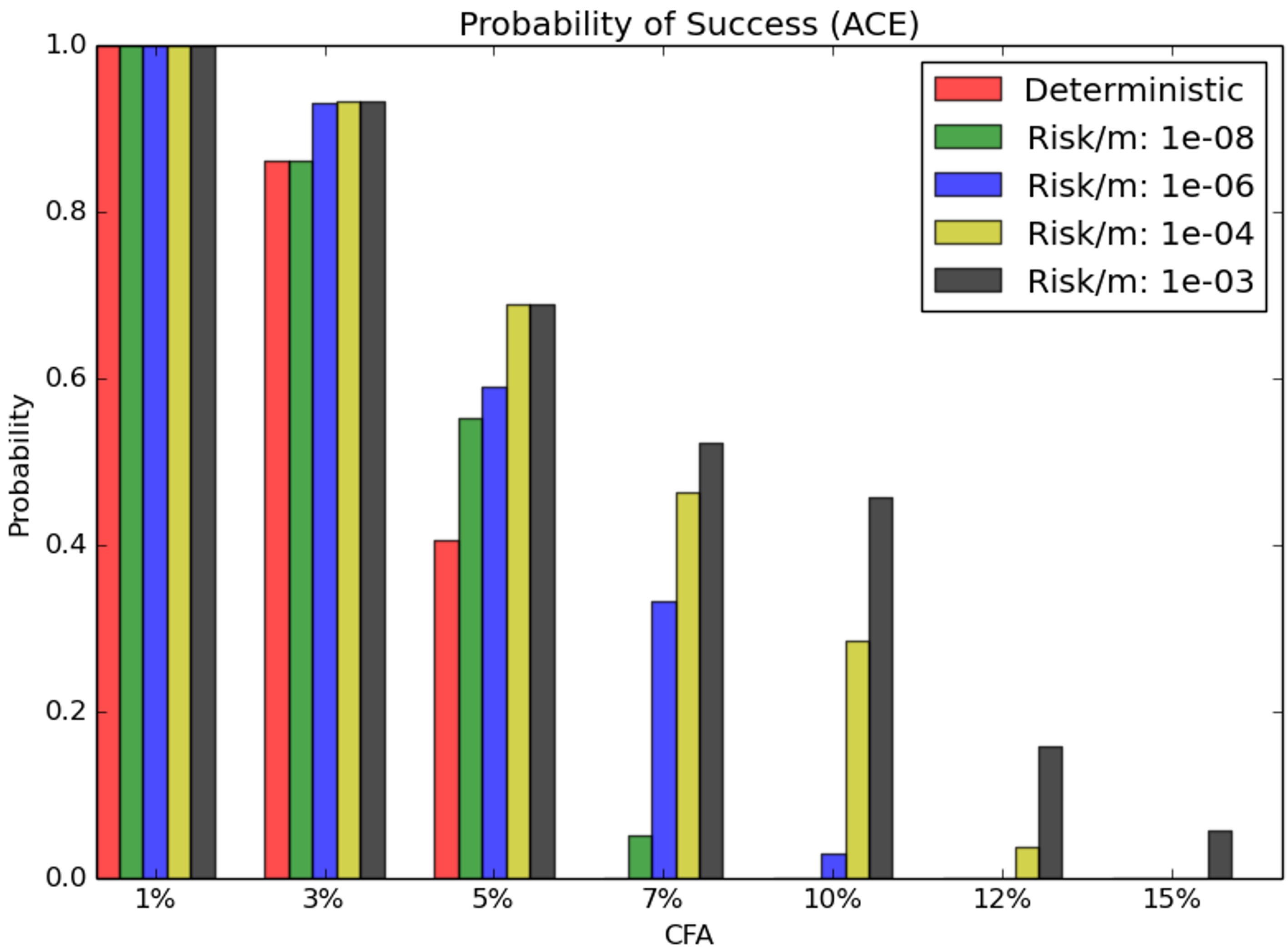
Risk/m (r): 1e-03

LEGEND

- Start Pose
- End Pose
- Failure: > r
- Failure: (0.75r, r)
- Failure: (0.5r, 0.75r)
- Failure: (0.25r, 0.5r)
- Failure: (0, 0.25r)

CFA: **7%**
Arc size: 3m
Map: 15mx15m
(Jezero Crater)

Results (ACE vs p-ACE)



Athena Rover

These results are from the Athena Rover model which is a small-scale testbed Mars Rover.